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AERIAL VOLUME TABLES
FOR HARDWOOD STANDS
IN THE CENTRAL STATES

BY

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TECHNICAL PAPER NO. 122

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MAY 1951

This report is from the

DIVISION OF FOREST ECONOMICS

Robert K. Winters, Division Chief

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Introduction

Effective use of aerial photos in aerial timber estimating requires volume tables based on variables that can be seen and measured on the photos. Three variables, stand height, average crown diameter, and density (the proportion of ground area covered by tree crowns) can be measured on aerial photos and are correlated with stand volume.

Aerial volume tables can be classified as (1) tree tables in which volumes for single trees are correlated with photo measurements of the same trees, or (2) stand-volume tables in which per-acre volumes computed from ground measurements are correlated with average per-acre measurements made on aerial photos. Each has its particular uses and deficiencies.

Tree tables have proved most usable in scattered stands of mature trees and with large-scale photographs. They can be constructed more easily than stand-volume tables. However, in medium- or well-stocked stands and with small- or medium-scale photographs, tree counts are time consuming and highly inaccurate. For many forest stands, therefore, it is faster and more accurate to make average measurements for a plot and to read an average per-acre volume from a stand-volume table, than to measure individual trees, look up the volume for an average tree, and multiply by a tree count. Since the primary reason for an aerial timber estimate is to determine stand volume more efficiently, the stand-volume table seems to be the more satisfactory.

During the past four years a number of stand-volume tables have been prepared and used at the Central States Forest Experiment Station. Although developed primarily to help in stand classification by the Forest Survey, they have been used with considerable success on a few aerial cruises. The tables vary somewhat according to the data used and the preciseness with which they were compiled, but tests indicate that a single aerial stand-volume table can be constructed and, with adjustments, can be used throughout the central hardwood region.

In the following pages appear board-foot and cubic-foot tables showing average gross stand volume per acre (including the volume in cull trees) for stands with given total height, crown diameter, and percent crown coverage.

Construction of Aerial Volume Tables

These stand-volume tables are based on a correlation of per-acre volumes from plots measured in the field with stand measurements of the same plots made on air photos. Field and photo measurements were made on 484 plots randomly distributed in the hardwood stands of Kentucky.

Photo Measurements

The photo measurements taken on 1-acre circular plots include:

1. Average total height of the dominant stand. This variable was originally selected because of the known correlation between merchantable and total height. A number of studies show that per-acre volume correlates best with this variable, and that average stand heights obtained from photo readings compare favorably with those obtained by Abney level readings in the field. Height measurements were made with a parallax wedge.^{1/}
2. Average crown diameter of trees in the dominant stand. This variable was selected because of the correlation between d.b.h. and visible crown diameter. Studies show fair correlation between stand volume and average crown diameter, though not as good as with total height. Measurements were made by means of a Crown Diameter Scale.^{2/}
3. Percent crown coverage of the dominant stand. This measurement was selected because it is one measure of stand density and is easier to use on aerial photos than a tree count. Studies show poorest over-all correlation between volume and crown coverage, but this variable was included because of its value in stands of below-medium density. Measurements were made by means of the Crown Density Scale.^{3/}

Although volume correlated best with total height, multiple correlation indicated that the table could be improved by using all three photo variables. Interpreters may vary 10 to 15 percent in their measurements of these variables on individual plots. To reduce this

^{1/} Rogers, Earl J. Use of the parallax wedge in measuring tree heights on vertical aerial photographs. Northeastern Forest Experiment Station. Forest Survey Note No. 1. 1946.

^{2/} Jensen, Chester E. Dot-type scale for measuring tree-crown diameters. Central States Forest Experiment Station. Station Note No. 48. 1948.

^{3/} Moessner, Karl E. Crown density scale for photo interpreters. Central States Forest Experiment Station. Station Note No. 52. 1949.

variation, three experienced interpreters made independent readings of each plot. These readings were averaged and this average was used in constructing the table.

Field Measurements

Field measurements^{4/} were made as part of the routine field work of the Forest Survey. Saw-timber trees were tallied by species, d.b.h., and log lengths on one-fifth acre circular plots. Pole trees were tallied by species and d.b.h. on one-tenth acre plots having the same center. Samples were taken of both saw-timber and pole trees. Species, d.b.h., form factor, total and merchantable height were recorded for each sample tree.

Computations

Per-acre volumes were computed from these field plots using the Mesavage-Girard form class tables and form class determined from the sample trees. Cubic volume was figured for all trees 5 inches d.b.h. and larger and includes the volume of poles to a 4-inch top diameter. The cubic volume of saw-timber trees includes sawlog volume plus tops and limbs to a 4-inch diameter. Board-foot volume is International 1/4-inch scale and includes hardwoods 11 inches d.b.h. and over to a variable merchantable top diameter that was never less than 8 inches.

Since the stand measured on the photos included all trees both sound and cull, gross volumes including cull trees were used in the table. The proportion of cull and cull trees varies considerably throughout the region, so it seemed that a more usable table would result if these deductions were made locally rather than included in the general table.

Correlations with Volume

The tables were constructed by the alinement chart method^{5/} of solving problems in curvilinear multiple correlation described by Bruce and Reineke.

Photo measurements made on 1-acre circular plots were compared with volumes computed from ground measurements of one-fifth and one-tenth acre concentric field plots using standard Forest Survey field data. Of course there might be considerable variation between individual plot volumes computed from one-fifth acre plots and those computed from an entire acre. Statistically, however, the averages from the large number of one-fifth acre plots used would tend to offset the volume variation in the individual one-fifth acre plots. The method had one very important advantage: the basic data cost relatively little because standard Forest Survey data were used.

^{4/} Becker, Maxwell E. Forest survey procedures for area and volume determination. Jour. Forestry 48(7):465-469. 1950.

^{5/} Bruce, D. and Reineke, L. H. Correlation alinement charts in forest research. U. S. Dept. Agr. Bul. 210. 1931.

The board-foot alinement chart (fig. 1) was adjusted to produce the cubic-foot alinement chart (fig. 2). Board-foot and cubic-foot tables read from these charts follow (tables 1 and 2).

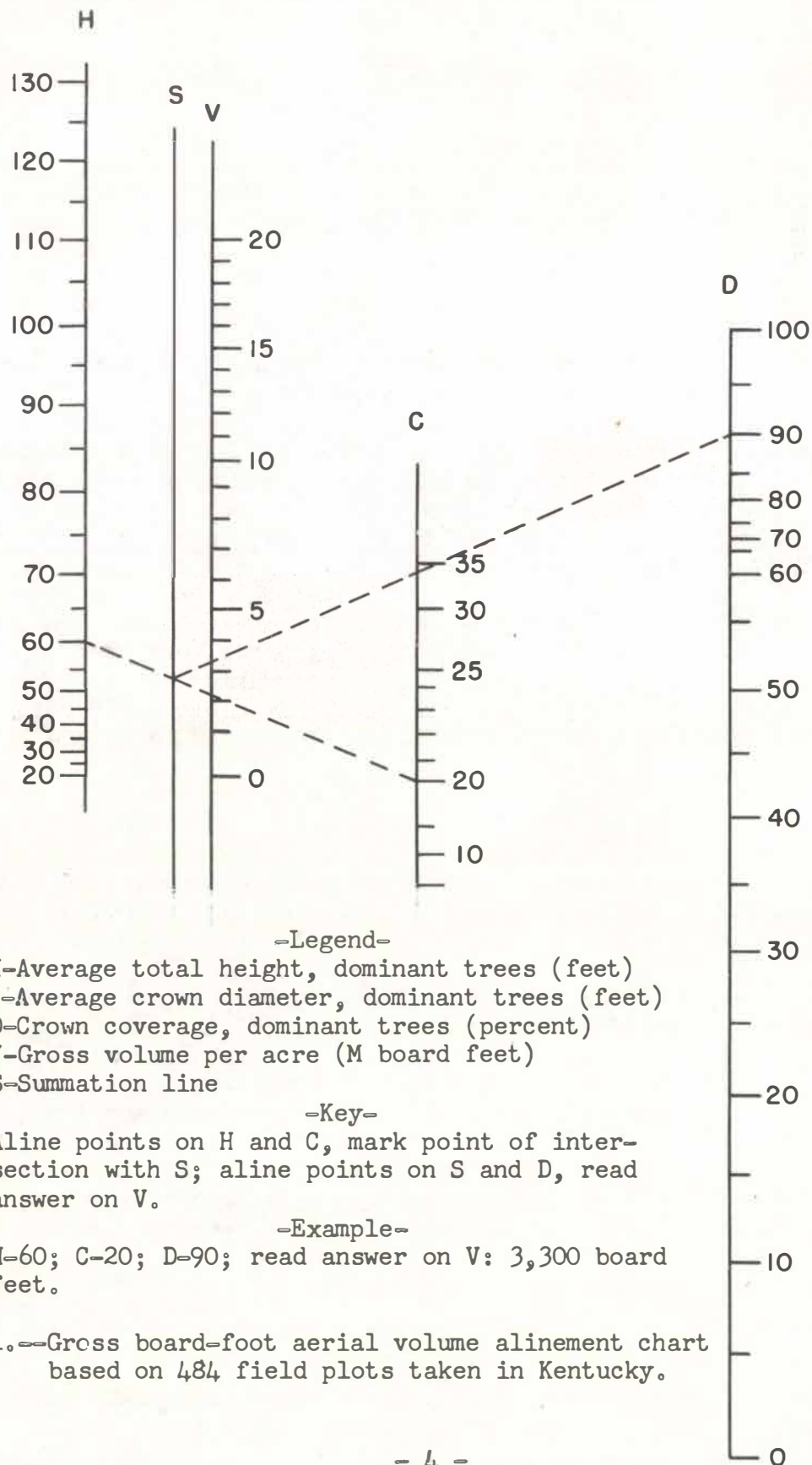


Figure 1.--Gross board-foot aerial volume alinement chart based on 484 field plots taken in Kentucky.

Table 1.—Gross board-foot volume per acre for Kentucky hardwood stands by average stand height, crown diameter, and crown coverage^{1/}

10-14 FOOT CROWN DIAMETER

Average stand height	Crown cover (Percent)			
Feet	15	35	55	85
40	-	+	5	10
50	+	5	15	20
60	10	20	25	30
70	25	35	40	45

15-19 FOOT CROWN DIAMETER

40	-	+	10	15
50	5	10	15	20
60	15	20	25	30
70	30	35	40	45
80	45	55	60	65

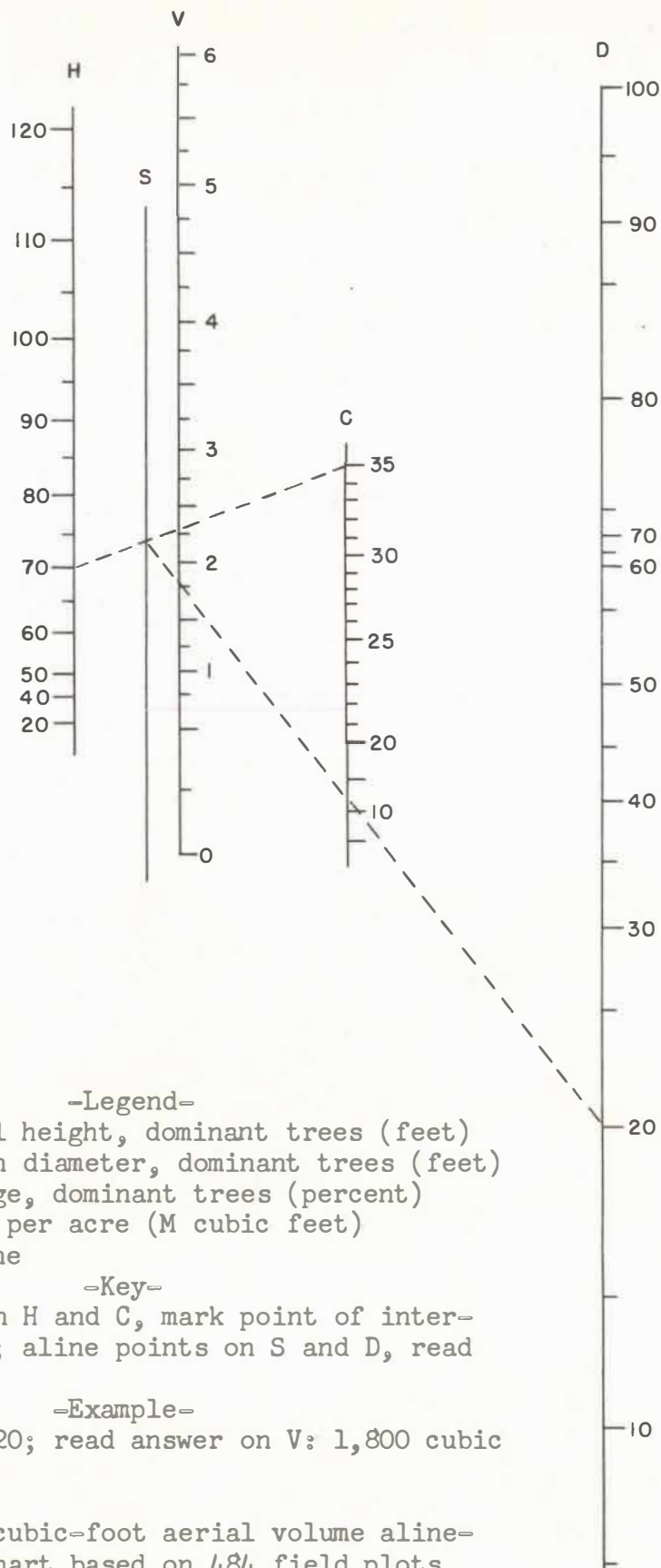
20-29 FOOT CROWN DIAMETER

40	5	10	20	25
50	15	20	25	30
60	25	30	35	40
70	40	45	50	55
80	60	65	70	75
90	75	85	90	95
100	95	105	110	115

+30 FOOT CROWN DIAMETER

50	20	30	35	40
60	35	40	45	50
70	50	55	60	65
80	65	75	80	85
90	85	95	100	105
100	105	115	125	130
110	130	140	150	155

^{1/} Figures within the blocked areas are based on field data.



-Legend-

H=Average total height, dominant trees (feet)
 C=Average crown diameter, dominant trees (feet)
 D=Crown coverage, dominant trees (percent)
 V=Gross volume per acre (M cubic feet)
 S=Summation line

-Key-

Aline points on H and C, mark point of intersection with S; aline points on S and D, read answer on V.

-Example-

H=70; C=35; D=20; read answer on V: 1,800 cubic feet.

Figure 2.—Gross cubic-foot aerial volume alignment chart based on 484 field plots taken in Kentucky.

Table 2. Gross cubic-foot volume per acre for Kentucky hardwood stands by average stand height, crown diameter, and crown coverage^{1/}

10-14 FOOT CROWN DIAMETER

Average stand height Feet	Crown cover (Percent)			
	15	35	55	85
	----- Ten cubic feet -----			
30	30	45	50	70
40	35	50	60	75
50	40	55	70	90
60	55	80	95	120
70	90	125	140	160

15-19 FOOT CROWN DIAMETER

30	35	45	55	75
40	40	50	65	85
50	45	60	75	100
60	60	85	105	120
70	100	130	150	165
80	150	175	190	210

20-29 FOOT CROWN DIAMETER

40	50	75	95	120
50	60	90	110	135
60	90	120	135	155
70	135	160	175	195
80	175	205	220	240
90	220	250	265	285
100	270	300	315	330

30 FOOT CROWN DIAMETER

40	85	120	135	155
50	105	175	150	170
60	130	160	170	195
70	170	200	215	235
80	215	240	260	280
90	260	285	300	320
100	305	330	345	360
110	360	380	395	415

^{1/} Figures within the blocked areas are based on field data.

Standard measures of the accuracy of these two aerial volume tables are given in the following tabulation:

	<u>Deviation</u>		<u>Standard error of</u>	
	<u>Average</u> (Percent*)	<u>Aggregate</u> (Percent)	<u>the estimate</u> (Units (Percent*) per acre)	
Gross volume				
Int'l. bd. ft.	41.83	-0.16	±2,603	±61.20
Gross volume				
Total cu. ft.	29.91	+0.85	±650	±43.19

*Expressed as a percent of the volume of the average plot.

Board- and cubic-foot volumes were obtained from the one-fifth acre field plots at the center of the acre measured on photographs. The rather high average deviations and standard error of the estimates are partly due to the difference in size of these plots. Per-acre averages read from the table are somewhat better than these measures would indicate.

Use of the Aerial Volume Table

As a first step in using these aerial volume tables, the photo interpreter must train himself to measure consistently on photos the three variables used in constructing the table. Experience has shown, however, that the best interpreters, using standard 1:20,000 scale summer photos of good quality may still vary 10-15 percent in their readings of these individual factors. There is little to be gained then by recording total heights in less than 10-foot classes, crown diameters in less than 5-foot classes, or crown coverage in less than 20-percent classes, when estimating on photos of this scale.

Average total height of the dominant stand is determined first since volume correlates best with this variable. Usually four or five of the dominant trees throughout the acre are measured and the average recorded to the nearest 10 feet. Measurements should be made with parallax wedge or other instrument of comparable accuracy.

Average crown diameter of the dominant stand is next obtained by averaging the crown diameter readings of four or five of the dominant trees on the acre. Readings are made with crown diameter scale and recorded to the nearest 5-foot class.

Finally the percent of the acre covered by crowns of the dominant stand is read by means of a crown density scale, and recorded to the nearest percent class.

The average per-acre volume for the stand can then be read directly from the aerial tables. The cubic- or board-foot table corresponding to the crown class is selected. Opposite total height and below crown coverage is found the average per-acre volume to the nearest 50 cubic or 500 board feet.

Tests of the Tables

An initial test of the table was made by comparing the independent estimates made by two photo interpreters with the volume measured on 70 field plots randomly selected in the hill country of southern Indiana. These plots, located in nine counties not far from the Kentucky line, were measured on air photos before field measurements were made.

Photo volumes were determined from these height, crown diameter, and crown coverage measurements using the aerial volume table for Kentucky. Field volumes were determined from field tallies and the Mesavage-Girard form factor volume tables developed in Kentucky and used in compiling the aerial volume table. The following tabulation shows the results:

	No. of <u>plots</u>	Total volume (Bd.ft.)	Aggregate error (Bd.ft.) (Percent)		Mean volume per acre (Bd.ft.)
Photo Interpreter A	70	310,200	200	+0.06	4431+388
Photo Interpreter B	70	295,700	14,300	-4.61	4224+368
Field Estimate	70	310,000	—	—	4429+548

Although this estimate was based on a small number of plots with volumes ranging from a few hundred to 35,000 board feet per acre, the aggregate errors are not great and the mean volumes are not significantly different.

To get a better idea of how the aerial table might work, a few generalized tests were made using photo measurements and field data from the routine Forest Survey work.^{6/}

Following are the results obtained by using the aerial table and a small number of saw-timber-size plots located within limited areas. Measurements were made by several different interpreters during routine work. No cutting had been done on the plots since the photographs were taken.

^{6/} Field volumes were computed by means of the Lake States International Cumulative Volume Tally. A study made on 10 percent of the plots used in the aerial table indicated that the Lake States form read 10 percent high compared to the Mesavage-Girard form factor tables developed from Kentucky data and used in constructing the aerial table. A 10 percent deduction was therefore made on the field volumes used in the tests.

<u>Location of sample</u>	<u>No of plots</u>	<u>Mean per-acre gross volumes</u>		<u>Difference between photo and field</u>	
		<u>photo</u> (Bd.ft.)	<u>field</u> (Bd.ft.*)	<u>photo</u> (Bd.ft.)	<u>field</u> (Percent*)
5 counties in southern Illinois	53	4255±286	4529±505	-274	- 6 0
11 counties in central Illinois	47	5083±270	5665±411	-582	-10.3
3 counties in southern Indiana	53	5613±389	6108±604	-495	- 8.1

*Based on the adjusted field volume.

Although the estimates are from 6 to 10 percent below the field, the difference between results obtained in various locations is slight, and in no case do the photo means vary significantly from those obtained in the field.

The following table shows the results obtained by a number of interpreters using a sample of 25 to 50 consecutive saw-timber plots unchanged since the date they were photographed.

<u>Number of plots</u>	<u>Mean per-acre gross volumes</u>		<u>Difference in photo and field volumes</u>	
	<u>photo</u> (Bd.ft.)	<u>field*</u> (Bd.ft.)	<u>photo</u> (Bd.ft.)	<u>field</u> (Percent)
50	5998	6314	- 316	- 5
50	5690	6530	- 840	-13
50	5668	5450	+ 218	+4
29	5362	5170	+ 192	+4
28	5614	5072	+ 542	+11
50	4114	5312	-1198	-23
50	3466	3753	- 287	- 8

*Adjusted for tabulae difference

Mean difference is 10 percent with a standard deviation of 7 percent. This indicates that a photo interpreter using only 50 plots could expect a mean volume within 17 percent of the field mean two-thirds of the time.

General tests of this type have not been made for the cubic-foot tables but limited trials indicate results would be at least as good.

Adjustment of Aerial Volumes

Experience indicates that these tables can be used to approximate gross volumes from air photos throughout much of the Central Hardwood region. The volumes given are averages, however, and cannot be expected to fit all conditions. Where more precise estimates are required, where net volumes are needed, or where stands vary widely in composition from those used in the table, adjustments of some type are needed. For some estimates a reasonable adjustment or breakdown of gross aerial volume can be made with factors from past experience. More detailed adjustments require the use of field plots. Where field plot data is available the entire table may be adjusted by adjusting the basic alignment chart. Although some of the procedure used in constructing the original chart must be repeated, the entire job can be done with fewer plots and correspondingly less cost than would be required for an original table. This method^{7/} is advisable where the table will be used for a number of surveys in the same general area.

When aerial surveys are made of small areas and when few plots are involved, it is usually best to adjust the mean volumes from the photos using a few field plots instead of attempting to adjust the entire table. Such adjustments have the obvious advantage of correcting the aerial volume for local cull and other variations in one operation. Field plots taken for this purpose will furnish percentages for estimates by species and d.b.h. class, as well as many other conventional details not directly readable on air photos.

When the plots measured on photos are stratified into a few classes easily recognized on photos, the data for adjustment can be obtained from very few field plots. The procedure for such an adjustment follows:

1. Volume for each selected plot measured on photos is read from the aerial table.
2. Plots are sorted by stand size, site, or some other classification, and a sample of several plots is drawn from each class and measured in the field.
3. Average photo and field volumes are determined for each classification and a correction factor computed for the class.
4. This correction is then applied to the mean photo volume computed from all photo plots in the class.
5. Species or other breakdowns of the adjusted volumes are then made for each stratification using percentages based on the field plot data.

^{7/} See appendix for detailed adjustment procedure.

Points to be Considered in Using the Tables

Volume estimating from photo measurements requires a different approach from that used in normal ground cruising. Precise measurements of d.b.h., merchantable height, and form factors, cannot be made directly on air photos. Even the recognition of species, or the simple classification of cull or sound trees is usually impractical. Yet the aerial estimator enjoys some distinct advantages. He can observe and classify the entire tract if necessary. By means of simple photo measurements, he can compare it with other tracts previously cruised on the ground. His measurements are few, his costs are low, and the intensity of his sampling can be stepped up without greatly increasing costs. But his approach must be by means of generalized tables and averages based upon previous ground surveys.

The tables presented in this paper are intended to be used for aerial estimating. Some limitations in their use, due in part to method of construction as well as to the scale and type of photos used in the work, are listed below:

1. Individual plot volumes read from the table may not agree with those determined from field measurements. Multiple correlation of photo-measured variables and field estimated volumes used in the table was approximately 0.75 and the average deviation of the individual plots was 42 percent of the average plot volume in the board-foot table. Estimating individual plots by means of such a table is comparable to estimating them from a yield table. However, mean per-acre volumes, not individual plot volumes, are the final objectives. Since the tabular averages are correlated with photo-measured plot variables, true volume for individual plots is an unnecessary refinement.
2. The tables have been extended beyond the data. Although effort was made to secure a fair distribution of plots, most of those used were concentrated in the middle ranges of the table. Volume estimates from plots which cover the normal distribution of photo measurements for this region should be reasonably close. Where plots estimated vary greatly from the average, for example, on large-volumed virgin or mature tracts, the estimated volumes may be inaccurate.
3. The tables are based on average species distribution. The method assumes that species composition will have little effect on average gross volume. Since individual hardwood species can rarely be identified on air photos, there is little advantage in attempting to build aerial tables for individual species. Where species composition varies widely from the normal distribution used in the table, average volumes may be inaccurate.
4. Standard errors of the means determined from tabular volumes cannot be compared to standard errors of means from individual field plots. The photo estimates are averages of means while field estimates are averages of individuals. For this reason the extremes do not appear in the photo volume estimates and the standard errors are usually one-third to three-quarters as large as those determined on the actual field plots.

Conclusions

1. Reasonably effective aerial volume tables can be constructed which will correlate the measurable photo variables of average total height, average crown diameter, and percent crown coverage with per-acre volumes determined from field plots.
2. These tables reflect average conditions over wide areas, and ordinarily require some adjustment for local use.
3. Adjustments can be made with much less effort than would be required to construct entirely new tables.
4. Although aerial volume tables of this type have limitations, they do give approximate volumes from air photos with little or no costly ground work.

Appendix

From 50 to 100 one-fifth acre plots will be needed for adjusting the chart. These should be distributed throughout the range of volume likely to be found in the area in which the chart will be used. If previously measured field plots can be accurately located on air photos, they can be used in the adjustment. Where such plots are not available, new plots may be located on the photos and sampled in the field. It is usually possible to select plots in accessible areas which will still represent the range of conditions likely to be encountered. Photo measurements of average total height, average crown diameter, and crown coverage of the dominant stand are then made for each plot. A volume for each plot is then computed from conventional field measurements. Field plots larger than one-fifth acre may be used where available. To simplify handling the data, use one 3- x 5-inch card for each plot and on it list the photo measurements, the corresponding volume read from the original alinement chart, and the new volume determined from field measurements.

Regraduate the volume axis of the basic alinement chart in this way:

1. Sort cards by table volume into 5 to 10 volume classes, depending on the number of plots to be used.
2. Total the field and table volumes for each class and obtain an average for each.
3. Plot average field volume over average table volume by class, curve the data, and regraduate the volume axis using the new field volume equivalents (fig. 3).
4. Read new volumes for the plots.

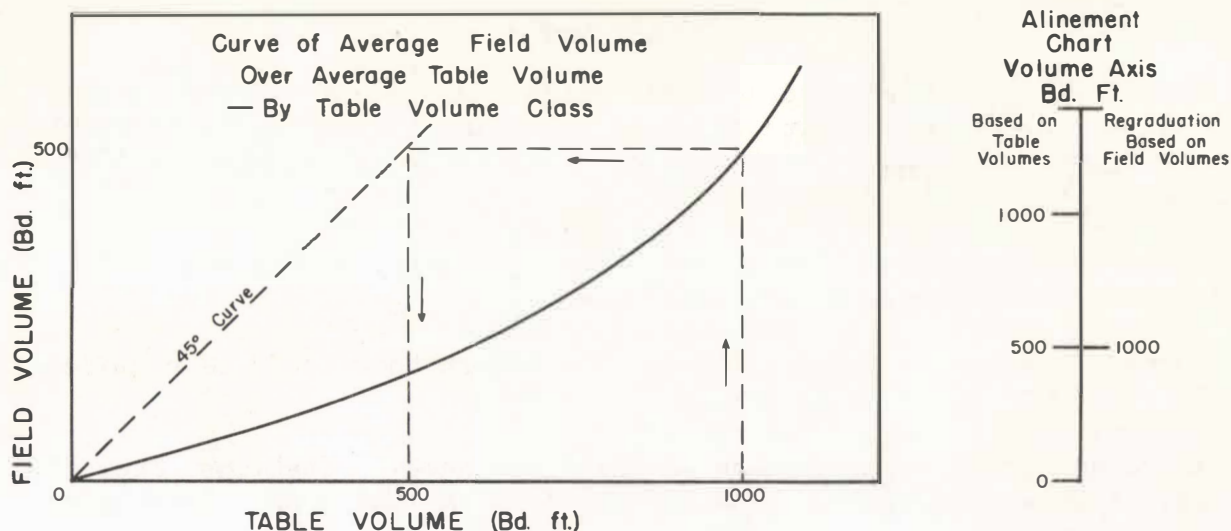


Figure 3.--In this example the curve of field volumes over table volumes lies below the perfect correlation (45°) curve. Selecting a point, field volume 500, table volume 1000, we shift it to the left until it lies on the 45° curve. It now reads field volume 500 over table volume 500. To adjust the chart we therefore compress the volume axis and place the new reading of 1000 opposite the old reading of 500.

After regraduating the volume axis, it is necessary to regraduate the three other axes: height, crown diameter, and crown coverage. To regraduate the height axis:

1. Average the heights for each of 5 to 10 height classes.
2. Average the new table volume and average the field volumes by these height classes.
3. Plot table volume over height, and field volume over height, on the same graph, using the averages obtained above.
4. Fit a curve through the tabular volume and a second through the field volume.
5. Regraduate the height axis (fig. 4).

The crown diameter and crown coverage axes are then regraduated in the same way. It is sometimes advisable to prepare these three curves before correcting any of the three axes and then correct somewhat less than the indicated amount on each. Since height and crown are interrelated, the full indicated correction, if made on each axis, may tend to over-correct the table. After the above corrections have been made on the three axes, reread the volume for each plot. Using these readings, regraduate the volume axis using the first procedure explained above.

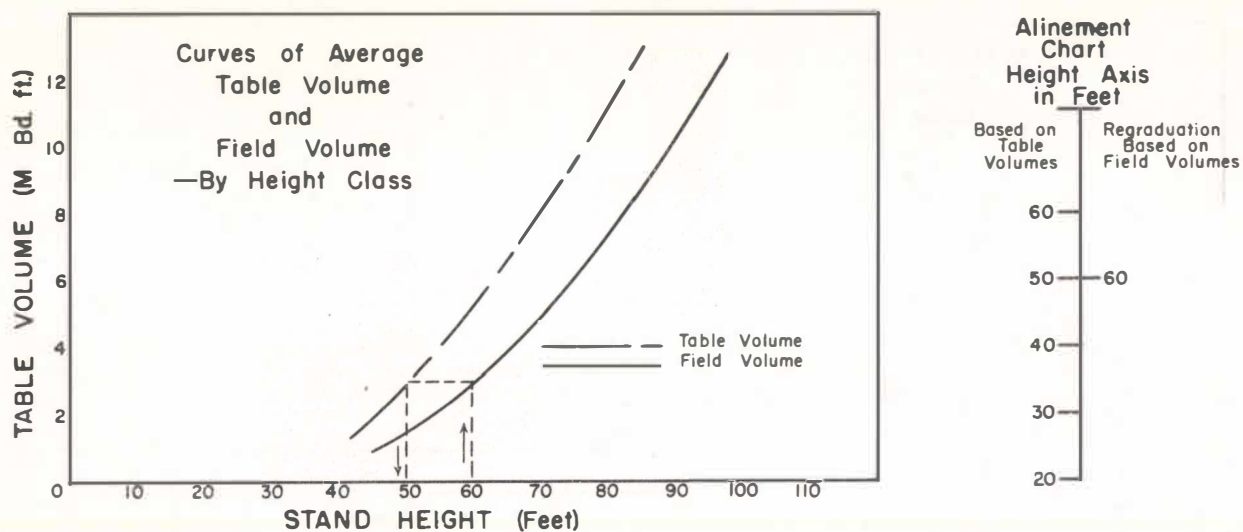


Figure 4.--In this example the curve field volume over height must be moved to the left to coincide with the curve table volume over height. The height axis must be compressed and the new figure of 60 plotted opposite the old reading of 50.

The results of the adjustment should be tested by plotting curves of field and table volume over height, crown diameter, and crown coverage classes, and by computing an aggregate deviation for the table. If the curves coincide reasonably well, and if the aggregate error is less than 1 percent, the adjustment is satisfactory. If obvious differences show up, the entire procedure outlined above should be repeated until no further improvement is shown.

A new table is then read from the chart.

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